PREVENTION AND DESTRUCTION OF MOSQUITOES.

[Prepared by direction of the Surgeon-General.]

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Its habit of feeding on the blood of man and other animals, the irritating character of its bite, and the more or less vague suspicion that it is connected in some way with the propagation of disease have always given the mosquito a certain sanitary and economic significance. But the demonstration in recent years of the essential part played by this insect in the propagation of filariasis (elephantiasis), malaria, yellow fever, and dengue—diseases which annually cause much human suffering and many deaths and, incidentally, an economic loss appalling to contemplate—has given great economic and sanitary importance to the problem of its extermination.

It is not proposed to discuss here all aspects of this problem; it is intended merely to outline the measures which have been found in actual practice to be relatively inexpensive, easily applied, and effective in reducing the number of mosquitoes to such a degree as to notably diminish the annoyance and discomfort caused by them and to reduce to a minimum the danger of disease conveyance.

Before beginning a campaign of mosquito extermination it is important to familiarize oneself with the fundamental facts in the life-history of these insects, for the measures which make a successful campaign possible are based upon these facts.

The mosquito.—The adult individuals of the various species differ markedly in their habits. Some are so commonly or almost exclusively found in or close to human habitations as to almost entitle them to be classed as domestic animals. Notable in this class are *Stegomyia calopus*—the yellow fever mosquito—and *Culex pungens*, the intermediary for *Filaria bancrofti* (filariasis) and for the virus of dengue. Others are never or only accidentally met with in or near human habitations. These are the swamp, marsh, or field species, the so-called sylvan or "wild" mosquitoes, of which *Ochlerotatus sollicitans* (= *Culex sollicitans*), the salt-marsh mosquito, is a well-known example. A third or semidomestic class may be encountered either in or near houses or in fields and swamps. This class includes the malaria-disseminating mosquitoes of the old genus *Anopheles*.

The adult insect may be carried to considerable distances by winds, but on its own wings it does not ordinarily travel outside of a radius of half a mile from its breeding place. This means that the destruction of all breeding places within this radius of a habitation will practically rid it of all but those mosquitoes which filter in or are brought in by winds from more or less distant marshes.

Mosquitoes breed in water in which they pass their larval ("wiggle-tail") and pupal stages. They never breed in damp grass, weeds, or bushes as has been popularly supposed, but frequently hide in these during the day. As might be inferred from their habits, the several species differ considerably in the character of the breeding places which they favor. The domestic species may be found breeding *in any collection of water* in or about the houses in which they lodge; they have been found in discarded tins, bottles, and broken crockery on the garbage heap; in buckets, tubs, barrels, cisterns, and wells; in baptismal and other fonts; in flowerpots and sagging roof gutters; in street and road-side puddles, gutters, and ditches; and in cesspools and sewers. The semidomestic species may occasionally be found breeding in tins, barrels, hoof prints, post holes, and holes in trees or tree stumps, but they usually prefer grass-bordered pools, slowly flowing ditches, the margins of lakes and streams, even such as are stocked with fish, provided the margins are shallow or are more or less choked with reeds and water plants so that the fish can not reach them. The sylvan or "wild" mosquitoes select breeding places of much the same character as do the semidomestic species with which they are not infrequently found associated, except that such breeding places are usually more or less remote from human habitations, in woods, swamps, and fresh or salt (brackish) coastal marshes.

In general, the food of mosquitoes consists of vegetable juices; unfortunately, the female of many species has developed a taste for blood, and indeed a feed of blood has become indispensable to some of these for the full development of their eggs. Remembering how all-compelling the generative instinct is, we can now understand why the *Stegomyia calopus*, for example, will, when disturbed, return again and again in an endeavor to obtain her fill of this life-giving fluid.

Having obtained her feed of blood she soon—in from a day or two to a week or ten days—seeks a suitable breeding place; here she deposits a variable number of eggs which, depending on the species, either float separately on their sides or up-ended and adhering together in irregular raft-like masses. Under ordinary conditions these hatch out in a day or two into larvæ or "wiggle-tails." The larva, although an aquatic animal, is a true air breather. The larva of *Anopheles* ordinarily feeds at the surface where it lies in an almost horizontal position, its tail and dorsal bristles touching the surface film and breathing through a breathing-siphon which is very short and insignificant in appearance.

The larvæ of the other species move about more or less actively, searching for food, but at intervals of a minute or two they may be seen to come to the surface for air and there hang, head down, attached by their more or less prominent conical breathing tubes to the surface film. After an existence of about a week as a larva it changes into a comma-shaped creature—the pupa. This is unprovided with a mouth and does not feed; but, except when disturbed, remains quietly at the surface, breathing through a pair of trumpet-shaped tubes which project from the dorsum of the thorax. This stage usually lasts two or three days and is terminated by the emergence of the adult winged insect from its pupal case through a rent in the region of the breathing tubes. The time from the laying of the egg to the emergence of the winged insect may therefore be as short

as nine days. Mosquitoes breed most abundantly or only during the summer, late spring, and early fall months.

Hibernation.—The way in which mosquitoes manage to pass through the rigors of the winter season probably varies with the different species; some, like the malarial *Anopheles*, hide in sheltered cellars or other out-of-the-way places, while others survive through the power of the larva or the egg to resist cold, even freezing, weather.

From the foregoing outline of the stages of development it is seen that the life of the mosquito may be broadly divided into an aquatic and an aerial stage, the former including the egg, larva ("wiggle-tail") and pupa, the latter being the adult, winged insect. Accordingly, the measures aimed at the destruction of the mosquito naturally fall into two classes: (a) Those directed against the larva and pupa—the aquatic stages—and (b) those directed against the adult.

MEASURES DIRECTED AGAINST THE LARVA AND PUPA.

For the extermination of mosquitoes the most effective measures are those which aim to destroy their breeding places and thus prevent their multiplication. For the best results both individual and communal effort is necessary, but the importance of individual effort alone can not be too much emphasized. The individual by attacking the problem on his own premises, grounds, or estate can do much not only to rid his own immediate neighborhood of mosquitoes and thereby increase his own comfort and guard himself from malaria, yellow fever, etc., but by setting an example he will stimulate his less enterprising neighbor, and thus derive additional benefit himself and indirectly confer a benefit on the community at large.

Natural breeding places.—Natural collections of water which do or may serve as breeding places are best dealt with by filling in or draining. In this way they are disposed of once and for all. For filling, inorganic refuse, such as cinders and ashes from houses and industrial establishments, may be employed, or sufficient earth may be dug from a near-by knoll or hill, care being observed that in so doing a depression capable of holding water is not made. Potholes in bowlders and irregularities in the rocky bed of a stream may be filled with concrete. Topographic conditions may render filling impracticable, or conditions may be such as to make draining of ponds, pools, or marshes the simpler and cheaper method. In this connection it may be observed that by draining of marshes is meant the draining of the pools of stagnant water, or in the case of coastal marshes the draining of the stagnant fishless pools that are beyond the reach of the ordinary tides and not the draining of the water-soaked soil itself. In order to be effective, ditches must be dug of sufficient depth to completely drain the pool or pools under treatment and with sufficient fall to prevent any stagnation in the course of the ditch itself. Where a sufficient fall is not obtainable, fishless pools may be connected with those containing fish or with a neighboring stream, so that the fish may freely enter. Similarly, many of the pools in coastal marshes may be rendered unfit as breeding places by ditching, so as to permit of their being freely scoured by the daily tides. Ditches must be inspected at frequent intervals and care taken to see that they do not become choked. Fish are among the most effective of the natural enemies of the mosquito. Advantage may be taken of this, either in the manner just described or

by directly stocking ponds or pools (ornamental lakes and fountains) with fish, such as minnows or goldfish. The margins of such pools must, however, be kept free of reeds and water plants, so as to permit the fish to reach their edges.

Where it is not possible to deal with pools and ponds in this way, and in the case of puddles, ditches, and the like, which it is not feasible to fill in or drain, resort may be had to coal (kerosene) oil. The oil may be poured on with an ordinary sprinkling pot or the surface sprayed with a hose. Sufficient oil should be used to cover the entire surface with a thin film. The oil thus spread on the surface acts as a stopper, shutting off the supply of air when the larvæ and pupæ come to the surface to breathe, and so causing their death by suffocation. As the oil is volatile and thus may become dissipated from the water surface within a few days and, furthermore, as the film which should be intact to be effective may be broken by winds, it is important to repeat the oiling regularly at intervals of not more than a week. It should always be borne in mind that oiling, though fairly efficient when properly carried out, is, in the nature of the problem, only a temporary, and in the end not an inexpensive, expedient.

Artificial breeding places.—In considering the methods of dealing with artificial collections of water which serve as mosquito-breeding places, it will almost invariably be found even where, in the absence of a public water supply, domestic storage is made necessary, that a variety of more or less useless water containers litter the premises. These and discarded tins, bottles, and the like should be absolutely abolished.

Whenever possible a closed system of water supply should be provided, for it is the most satisfactory way of doing away with the need of cisterns, barrels, and tubs. Where this is not, for one reason or another, practicable and domestic storage is a necessity, care should be taken to prevent the mosquito from gaining access to the water. Barrels, where these are in use, should be provided with tightly fitting covers. Burlap, sheeting, or several thicknesses of cheese cloth held in place by a well-fitting hoop serve this purpose very well. Wooden covers are unsatisfactory; they are rarely made to fit accurately enough to keep out the mosquito, and this defect is enhanced by the reasonable certainty that the wood will warp, making the cover worse than useless. More satisfactory than the wooden cover is one made of light galvanized sheet iron, the central portion of which may be wire gauze. The rim of the barrel should be trimmed to remove any irregularities that might prevent the cover from fitting evenly all around. Whatever the form of cover employed it should not be removed except for cleaning or refilling the barrel. The water should be drawn from a spigot. Where the water is very turbid and must undergo sedimentation before being used, several barrels should be provided for its storage and the water used from each barrel in turn. In such a case also the spigot should be placed about a foot from the bottom, so that the sediment need not be disturbed as the water is drawn off for use. Wells should be provided with tight covers and the water drawn by pumps.

Where cisterns or tanks are used these also should be provided with an accurately fitting cover, which should be inspected frequently to see, if wood, that seams are not opened up and cracks formed, as the result of warping and shrinkage from drying. Where warping and

shrinkage are likely to take place, as they almost certainly are in a hot, dry season, the cover should be reenforced by carefully tacking down and inclosing the upper foot of the tank with wire gauze of a mesh having not less than twenty strands to the inch. The wire gauze used may be iron, as this is the cheapest; but it rusts readily and is likely to require frequent renewals, so that galvanized iron, though somewhat more expensive, is really cheaper in the end. The inlet to the tank or cistern should be provided with a cap of the same close-meshed wire gauze, which may, if necessary to prevent its choking with leaves, etc., be protected by another and coarser meshed cap of stout wire. As an additional precaution, the inlet pipe should be long and extend well below the water level. In cases of emergency, as in times of epidemics of either yellow fever or dengue, where the permanent measures for preventing mosquito-breeding have been neglected, covering the surface of the water in the barrels, tanks, and cisterns with coal oil in the manner already described has been resorted to and has given fair results, but as the oil gives the water a slightly disagreeable odor and taste and is on that account at times objected to, the use of oil for this purpose can not be regarded as other than an emergency measure.

Cesspools and privy vaults should be done away with by providing dry-earth closets, or a sewerage system. Where this has not yet been done or can not for one reason or another be done, the cesspools should be frequently and copiously oiled.

MEASURES AIMED AT THE DESTRUCTION OF THE ADULT MOSQUITO.

For practical purposes, we have at command three substances which, though not ideal, serve reasonably well for the destruction of mosquitoes in a confined space. These substances are sulphur dioxide, pyrethrum powder, and phenol-camphor ("Mim's Culicide").

Sulphur dioxide.—This is a gas which is generated by burning sulphur in the air. It is a very efficient and on the whole a most useful insecticide, but its usefulness is restricted somewhat by its corrosive action on metals, bleaching effect on colors, and rotting effect on fabrics, especially in the presence of moisture. Its use, therefore, is largely limited to the fumigation of ships' holds, lofts, attics, cellars, halls, kitchens, bedrooms, and other places in which there are no paintings, valuable fabrics, or bright metal surfaces to be injured by it. In a dry climate, or in dry weather, and when the sulphur used for its generation can be burned in the absence of water, as it always should be where its insecticidal effect alone is desired, its use may be extended to the fumigation of libraries and living rooms with practically no danger of causing serious injury to books, metals, or fabrics, especially in the relatively small proportions and for the short exposure which suffice for this purpose.

The space to be fumigated should be measured, the cubic capacity calculated, and the sulphur apportioned on the basis of 1 pound to each 1,000 cubic feet. The sulphur is best burned in shallow pots of iron or tin, and in order to avoid the danger of scorching the floor or of fire from the spluttering of the sulphur, these should be set on bricks, which may be placed in the center of a circular layer of sand directly on the floor, or better, in a tub. The pots should not be stood in water, as is done when a bactericidal effect is desired. It should be remem-

bered that the rapidity of combustion depends on the extent of surface exposed to the air; and as it is desirable to evolve the maximum volume of fumes in the shortest possible time it is important, if the space to be fumigated is large and much sulphur is to be burned, to distribute it among several pots. The amount apportioned to any one pot should not be more than will cover the bottom to a depth of 1 to 1½ inches if the flowers of sulphur is used, or with not more than one layer of rolls if the roll sulphur is employed. If the amount of sulphur apportioned to a pot is greater than this it will take too long to burn, thus requiring an unduly prolonged exposure. Using the sulphur in the proportion of 1 pound to 1,000 cubic feet, the exposure should be for two hours, counting from the time the last exit is closed. The sulphur is ignited by first pouring a little strong alcohol (1 ounce of 95 per cent is enough) over it and setting fire to this with a match.

Pyrethrum powder.—When pure pyrethrum powder is ignited it smolders, giving off fumes which stun but do not absolutely kill all mosquitoes. It is not therefore an absolutely dependable insecticide, while its cost is at the same time considerable. Its uncertainty and its cost restrict its field of usefulness. Another objection to it is the deposit of a slight brown film on all exposed surfaces which occasionally follows its use.

Pyrethrum powder has heretofore been employed in those cases where sulphur could not be used because of the danger of serious damage to paintings, fabrics, tapestries, musical and other instruments, upholstered furniture and the like. It is used in the proportion of 2 pounds to 1,000 cubic feet, the exposure being for two hours. As its insecticidal effect is uncertain, it is necessary to carefully sweep up and burn all the mosquitoes that have been stunned and are apparently dead immediately after the fumigation. Most of these mosquitoes will be found on the window sash, window sill, or on the floor close to the window, where they go, attracted by the light, in their efforts to find an exit to escape the fumes. Advantage should be taken of this tendency of the mosquito to seek the light by darkening all but one window and by placing on the floor under this and on the sill sheets of paper on which some adhesive preparation has been spread. A satisfactory adhesive preparation may be made by dissolving with the aid of heat 65 parts of colophony resin in 35 parts of castor oil, as given in Hager's Handbuch. This simplifies the collection of the fallen insects subsequent to the fumigation. The required amount of powder is distributed in pots (tin dairy pans serve the purpose admirably) and ignited by setting fire to the alcohol, which should first be sprinkled over it. The quantity apportioned to any one pot or pan should not exceed 1½ inches in depth if the exposure is to be for two hours. As in the case of sulphur, the pots or pans should be set on bricks, to prevent scorching the floor.

Phenol-camphor ("Mim's Culicide").—This is a liquid produced by rubbing up equal weights of phenol crystals and camphor. It may perhaps be more readily prepared by first liquefying the phenol by gentle heat and then pouring it over the camphor, which it then dissolves. This preparation was first used on a considerable scale toward the close of the yellow fever epidemic of 1905 at the suggestion of City Chemist Mim, of New Orleans. When moderately heated it gives off dense fumes which rise rapidly, diffuse, and after thirty to sixty

minutes, depending on the amount employed and the temperature of the air, condense and are deposited as a slight moisture on all exposed surfaces. The effect of these fumes on mosquitoes has been studied by Berry and Francis. In the proportions found practically useful these fumes act like those of pyrethrum; they stun, but do not invariably kill. The fumes are irritating to the mucous membranes, especially of the eyes, and may cause mild symptoms of phenol poisoning in susceptible individuals if much exposed to their inhalation. They renew the brightness and temporarily soften the varnish of surfaces on which they condense. Because of these limitations, and furthermore because of its slight power of diffusion and relatively high cost, it, like pyrethrum, can not displace sulphur except in the field of house fumigation where sulphur, on account of its injurious properties, can not be employed. As compared with pyrethrum, phenol-camphor is less expensive, more certain, and not so objectionable to the housekeeper. It has the drawback, however, that bedchambers must be freely ventilated for several hours after its use before they are altogether safe to sleep in; that it requires special apparatus and a little more care and intelligence in its use, and is, on that account, a trifle more troublesome; and, finally, if overheated it may take fire spontaneously. For use on a large scale, as in times of epidemic, in the hands of trained fumigators, phenol-camphor is on the whole to be preferred to pyrethrum, because it is more easily transportable on account of the small bulk required and because the fumes condensing quickly a room may if desired be entered in an hour and the apparatus removed, thus making it possible to fumigate a larger number of rooms in a given time with less labor than in the case of either sulphur or pyrethrum.

It should be employed in the proportion of 4 ounces to every 1,000 cubic feet. In this proportion the film of condensation is slight and is rapidly dissipated after the doors and windows are opened, which should be freely done after an exposure of two hours. As in the case of pyrethrum, sheets of paper preferably adhesive should be placed under windows and on window sills and the fallen mosquitoes carefully swept up, collected, and burnt. The phenol-camphor apportioned to the room to be fumigated should be distributed in agate-ware basins, not more than 8 to 10 ounces to any one basin. The basin with the proper proportion of the liquid is then set over an alcohol or other lamp at such an elevation and in such a manner as will permit of a rapid evolution of the fumes, yet not heat the basin so quickly as to cause the liquid to become overheated and take fire spontaneously. These points must first be determined experimentally for each type of lamp used. One of the small brass alcohol vapor lamps to be found on the market serves excellently. When one of these is used it should, as a safeguard against accidents, be stood in a tin dairy pan containing about one-half inch of water. A tripod to hold the basin and also act as a chimney for conducting the heat may be satisfactorily improvised by using a section of galvanized-iron stovepipe, at one end of which portions are cut out so as to form legs of a length equal to the height of the lamp. The stovepipe should be of such a length as to support the basin containing the phenol-camphor about 10 inches above the flame of this type of lamp. Just below the upper margin of the pipe a series of holes is punched to provide for draft.

Preparation of room for fumigation.— In the use of any of these substances the space to be fumigated must be made tight, not only by closing all doors, windows, and other openings, but also, if need be, by pasting strips or sheets of paper over cracks, so that neither the mosquitoes to be killed nor the fumes employed to kill them can escape.

This should invariably be attended to before the fumigation is begun. Closets, in which mosquitoes frequently hide, should be opened so that the fumes can freely penetrate, and large pieces of furniture should be moved away from the walls for the same reason. There is, of course, no objection to removing fabrics, paintings, instruments, or other objects from the room, but, except when sulphur is used, there is no use in doing so.

Advantage may in some instances be taken of the fact that at summer temperature a mosquito rarely or never survives deprivation of food and water for from five to seven days, to destroy mosquitoes by closing and keeping a room sealed for a period of not less than ten days, being careful before sealing to remove from such room anything that may serve as food and all water and objects that may be damp. Care should, of course, be taken to see that the seal remains unbroken throughout this period.

Screening.—In order to minimize or to do away with the need for repeated fumigations, it is necessary to carefully screen all outside windows and doors. The main entrance should in addition be guarded by a screened vestibule of such a depth as to make it impossible for a person to hold both doors open at the same time. The screens should be of not less than 20 strands to the inch. Iron wire is cheapest considering first cost alone, but it will hardly last a season unless painted, in which case the size of the mesh is considerably reduced and to that extent interferes with ventilation, a serious objection in hot weather or a tropical climate. The galvanized-iron wire, though somewhat more expensive, is much to be preferred on account of its greater durability. Where the consideration of first cost may be ignored, brass or bronze wire may be selected, either of which will be found to last almost indefinitely.

Legislation.—The importance of the problem not only justifies, but in many instances urgently demands, that States and local communities supplement and strengthen their sanitary codes by enacting laws and ordinances aimed at the eradication of the mosquito. This is of peculiar importance in our Southern States, where the morbidity and mortality from malaria alone cause annually an enormous economic loss. Furthermore, appropriate legislation of this nature intelligently enforced gives the best possible assurance against the recurrence of epidemics of yellow fever and dengue. The law should declare all mosquito-breeding places nuisances prejudicial to the public health and should authorize the proper sanitary authority to draw up and enforce under appropriate penalty suitable regulations for their prevention and abatement. A few States and several municipalities have seen the wisdom of this and have placed this much-needed law on their statute books.

Organization.—The work should be under the direction of one with executive ability and a thorough understanding of the problem. He should have assistants who, under his direction, should have charge of the following divisions of the work:

1. Division of engineering, corresponding to the department of engineering of municipal organizations. This division should be charged with the duty of mapping out the location of natural breeding places, and their destruction by filling in or draining.

2. Artificial breeding places.—This division should be charged with the inspection of premises for the purpose of locating artificial breeding places, and for reporting failures to comply with the local ordinances, either with respect to the covering or screening of cisterns, wells, barrels, etc., used for the domestic storage of water, or the continued maintenance of these where public-water supply and sewerage exist. This division should also be charged with the duty of collecting and burying or otherwise disposing of garbage, paying particular attention to the collection of discarded tins, bottles, crockery, and the like.

3. Oiling division.—The duty of this division should be the oiling of all possible breeding places that can not be treated in one of the other more satisfactory ways, or those for which other treatment is proposed, but not yet executed.

The foregoing outline is presented merely as a skeleton and not with any idea that it is complete or final. Its purpose is that of a hint to those who are without experience in this line of work. It is likely that there are but few places to which it is entirely adapted in the exact form here proposed; the scheme which it suggests, however, will be found essential to any plan however different it may appear.

A campaign of education, which may constitute the duty of still another division, is an important element in the successful prosecution of the work. The interest of the public should be aroused through the public press and the circulation of leaflets, and by means of illustrated lectures. Every effort should be made to arouse the interest and obtain the cooperation of all classes and groups of citizens.

When to begin work.—Work may, of course, be begun at any time. It is best, however, to begin early in the spring. At this time it is well to burn the marsh weeds or grass in order to kill as many as possible of the hibernating eggs or larvæ in the thawing mud or pool bottoms, and it is well also to fumigate cellars, attics, and outhouses in order to kill the hibernating *Anopheles* or *Stegomyia*. The work of eradication should then be vigorously pressed and carried on through the summer well into the fall. In subtropical and tropical regions the work has, of course, to be carried on throughout the year, as the breeding of mosquitoes is but little, or not at all, affected by the change of season. Finally it may be said that valuable pioneer work has been done and encouraging results have been obtained at several points on Long Island, Staten Island, and in New Jersey.